Paraxial Schematic Eye Models for 7- and 14-Year-Old Chinese Children

Shi-Ming Li,[1] Ningli Wang,[1] Yuehua Zhou,[1] Si-Yuan Li,[1] Meng-Tian Kang,[1] Luo-Ru Liu,[2] He Li,[2] Yun-Yun Sun,[1] Bo Meng,[3] Si-Yan Zhan,[3] and David A. Atchison[4]

[1]Beijing Tongren Eye Center, Beijing Tongren Hospital, Capital Medical University, Beijing, China
[2]Anyang Eye Hospital, Anyang, Henan Province, China
[3]Department of Epidemiology and Health Statistics, Peking University School of Public Health, Beijing, China
[4]School of Optometry & Vision Science and Institute of Health & Biomedical Innovation, Queensland University of Technology, Kelvin Grove, Queensland, Australia

Correspondence: Shi-Ming Li, Beijing Tongren Eye Center, Beijing Tongren Hospital, Capital Medical University, Beijing, China, 100730; lishiming81@163.com.
David A. Atchison, School of Optometry & Vision Science and Institute of Health and Biomedical Innovation, Queensland University of Technology, Kelvin Grove, QLD, Australia; d.atchison@qut.edu.au.

Submitted: January 11, 2015
Accepted: April 5, 2015

Citation: Li S-M, Wang N, Zhou Y, et al. Paraxial schematic eye models for 7- and 14-year-old Chinese children. *Invest Ophthalmol Vis Sci.* 2015;56:3577–3583. DOI:10.1167/iovs.15-16428

Purpose. To develop three-surface paraxial schematic eyes with different ages and sexes based on data for 7- and 14-year-old Chinese children from the Anyang Childhood Eye Study.

Methods. Six sets of paraxial schematic eyes, including 7-year-old eyes, 7-year-old male eyes, 7-year-old female eyes, 14-year-old eyes, 14-year-old male eyes, and 14-year-old female eyes, were developed. Both refraction-dependent and emmetropic eye models were developed, with the former using linear dependence of ocular parameters on refraction.

Results. A total of 2059 grade 1 children (boys 58%) and 1536 grade 8 children (boys 49%) were included, with mean age of 7.1 ± 0.4 and 13.7 ± 0.5 years, respectively. Changes in these schematic eyes with aging are increased anterior chamber depth, decreased lens thickness, increased vitreous chamber depth, increased axial length, and decreased lens equivalent power. Male schematic eyes have deeper anterior chamber depth, longer vitreous chamber depth, longer axial length, and lower lens equivalent power than female schematic eyes. Changes in the schematic eyes with positive increase in refraction are decreased anterior chamber depth, increased lens thickness, decreased vitreous chamber depth, decreased axial length, increased corneal radius of curvature, and increased lens power. In general, the emmetropic schematic eyes have biometric parameters similar to those arising from regression fits for the refraction-dependent schematic eyes.

Conclusions. The paraxial schematic eyes of Chinese children may be useful for myopia research and for facilitating comparison with other children with the same or different racial backgrounds and living in different places.

Keywords: modeling, myopia, refraction, schematic eyes

Myopia is the condition in which the length of an eye is too great for its power. Light from a distant object focuses in front of the retina, causing blurred vision. During the childhood years, a process of emmetropization takes place, in which there is a gradual matching of the various intraocular distances and refractive components; myopia is a consequence of the failure of this to occur.[1] Although the optical consequences of myopia can be corrected by a range of optical interventions, myopia has emerged as a global public health problem in recent decades because of its association with ocular diseases that can cause irreversible visual impairment.[2]

In recent decades, many population-based studies have been performed to compile data sets of ocular biometric parameters and refraction in children. These studies have been conducted in regions with high prevalence of childhood myopia such as Taiwan,[3] Singapore,[4] and China,[5,6] as well as in Australia[7] and the United States,[8,9] where prevalence of myopia is much lower. These studies have found differences between the sexes, with boys having longer axial lengths than girls at 6 to 9 years (mean 7 years)—approximately 0.5 mm[4,7,8]—and older children having more myopia and longer axial lengths than younger children.[3,8]

No attention has been given to constructing schematic eyes based on children's data and exploring their use in myopia research. Establishing schematic eyes of a particular group might be helpful for facilitating comparison with other children with the same or different racial background and living in different places. In Anyang, a city located in central China with a socioeconomic status close to the national average, we have established two cohorts to collect the ocular biometry and refraction data annually in school-aged children,[6] with extensive evaluation of data for the grade 1 and grade 8 groups.[10] We used the baseline data for grade 1 and grade 8 children to construct schematic eyes.

Materials and Methods

Subjects and Measurements

At baseline, 2893 grade 1 children and 2267 grade 7 children were examined. They are being followed annually for 3 to 5 years. Only the data for the right eyes were used. Full biometric information was available for 3995 children, consisting of 2059 grade 1 children (boys 58%) and 1536 grade 8 children (boys

49%). The mean ages were 7.1 ± 0.4 and 13.7 ± 0.5 years, respectively, and these children are referred to as the 7- and 14-year-old groups. For refraction, the means, standard deviations, and ranges of spherical equivalent refraction were: 7-year-old boys, +0.93 ± 1.04 diopters (D), −6.50 to +7.38 D; 7-year-old girls, +0.96 ± 1.05 D, −5.63 to +8.63 D; 14-year-old boys, −1.91 ± 2.14 D, −9.38 to +5.50 D; 14-year-old girls −2.31 ± 2.13 D, −10.75 to +6.38 D. Astigmatism was −0.50 ± 0.49 D (−3.75 to 0 D) in the 7-year-old group and −0.56 ± 0.58 D (−4.75 to 0 D) in the 14-year-old group. There was a myopic shift of 3.1 D from the younger group to the older group, and in the older group the girls were significantly more myopic than the boys by 0.4 D. The dispersions of refraction were twice as large in the older group as in the younger group.

For an emmetropic subgroup, with emmetropia defined as spherical equivalent refraction (SE) −0.5 D < SE < +0.5 D, full biometric information was available for 515 children, consisting of 318 seven-year-old children (boys 58%) and 197 fourteen-year-old children (boys 52%).

The methods have been described previously.[10] In brief, the Lenstar LS900 (Haag-Streit, Koeniz, Switzerland) was used to measure corneal power (1.3375 index), corneal thickness, anterior chamber depth, lens thickness, and axial length in the uncyclopleged state; and the HRK7000A autorefractor (Huvitz, Gunpo, South Korea) was used to measure refraction referenced to the spectacle plane 12 mm in front of the cornea in the cyclopleged state.

Ray Tracing and Modeling

The parameters that were measured directly (taken from the Lenstar instrument) were the corneal thickness, anterior chamber depth, lens thickness, axial length, and corneal power. Assumed parameters were the refractive indices of the cornea/anterior chamber, lens, and vitreous. Calculated parameters were corneal radius of curvature, lens power, and lens radii of curvature.

Analysis involved paraxial ray tracing from infinity through the ophthalmic correction and eye to the retinas of three-refracting-surface model eyes, based on the Gullstrand-Emsley eye with a refractive index of 1.333… (or 4/3) for the cornea/anterior chamber and vitreous chamber, and a refractive index of 1.416 for the lens. The effective anterior chamber depth was taken as the sum of the corneal thickness and the anterior chamber depth. Additional parameters were the vitreous chamber depth, v_L, derived from the other distances, mean corneal power at 1.333… index, and the mean anterior corneal radius of curvature derived from the corneal power.

To determine axial length, the Lenstar measures to the retinal pigment epithelium and subtracts 0.200 mm to allow for retinal thickness. To calculate lens power, we put the 0.200 mm back; otherwise lens powers are overestimated by approximately 0.9 D (see Equations 3 and 4 below).

We assumed that the ratios of surface powers of the lens to that of its equivalent power were the same as for the Gullstrand-Emsley eye. In the Bennett[11] approach and for the Gullstrand-Emsley eye, the distances e and e' of the first and second principal planes of the lens from their respective surfaces are given by

$$e = 0.596345594\, t_L \quad (1)$$

$$e' = -0.35780736\, t_L, \quad (2)$$

where t_L is lens thickness. Ray tracing from infinity to the first principal plane gives the object reduced vergence L_L at this position, while the image reduced vergence is given by

$$L'_L = n_v/(l'_v - e'), \quad (3)$$

where n_v is vitreous index and l'_v is the distance from the second principal plane of the lens to the retinal pigment epithelium. Equivalent lens power F_L is given by

$$F_L = L'_L - L_L. \quad (4)$$

Lens power was used to determine lens surface powers F_1 and F_2 and lens surface radii of curvature r_{L1} and r_{L2} as

$$F_1 = -n_L e' F_L/(n_{aq} t_L) \quad (5a)$$

$$r_1 = (n_L - n_{aq})/F_1 \quad (5b)$$

$$F_2 = n_L e F_L/(n_v t_L) \quad (6a)$$

$$r_2 = (n_v - n_L)/F_2, \quad (6b)$$

where n_{aq} is aqueous index. The lens surface radii of curvature have little anatomical meaning, but are necessary to complete models.

Six refraction-dependent schematic eyes were developed for the total group: a 7-year-old eye, a 7-year-old male eye, a 7-year-old female eye, a 14-year-old eye, a 14-year-old male eye, and a 14-year-old female eye. Linear fits were made for distances and radii of curvature as a function of refraction. Based on these fits, corneal power F_c and equivalent lens powers F_L were determined as

$$F_c = (n_{aq} - 1)/r_c \quad (7)$$

$$F_L = F_1 + F_2 - (t_L/n_L)F_1F_2, \quad (8)$$

where r_c is anterior corneal radius of curvature, and F_1 and F_2 are determined from Equations 5b and 6b. This estimate for F_L is slightly different from that given by Equation (4). Linear fits for these powers were made as a function of refraction.

The mismatch v_{error} between measured and calculated vitreous chamber depth was determined as

$$v_{error} = v_{cal} - v, \quad (9)$$

where v_{cal} was derived from ray tracing and v is given by the model fits.

Six emmetropic schematic eyes were developed. The eye models used the appropriate mean parameters of distances and radii of curvature, with rounding to the nearest 0.01 mm except for corneal thickness, which was rounded to the nearest 0.001 mm. Some slight deviations from these values, such as changing the refraction to near zero, are described below. To account for the slight male bias, non-sex-based emmetropic eyes used the averages of male and female parameters rather the mean parameters of all eyes of an age group.

Results

Modeling Across the Refraction Range

Table 1 shows linear fits for distances, radii of curvature, and corneal and equivalent lens powers as a function of refraction.

Because of the large number of subjects, fits were significant at R^2 values as low as ≈0.002 for all children in an age group and ≈0.004 for single sexes. For each age group and its separate sexes, corneal thickness did not change

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Table 1. Refraction-Dependent Eye Models

	7-Year-Olds	7-Year-Old Boys	7-Year-Old Girls	14-Year-Olds	14-Year-Old Boys	14-Year-Old Girls
Distances, mm						
Cornea	0.54 **<0.001**	0.542 **<0.001**	0.538 **<0.001**	0.55 **0.001**	0.552 **<0.001**	0.548 **0.003**
Anterior chamber	$2.991 - 0.0986R_x$ 0.183	$3.017 - 0.0880R_x$ 0.16	$2.954 - 0.1011R_x$ 0.224	$3.093 - 0.0428R_x$ 0.149	$3.150 - 0.0441R_x$ 0.159	$3.027 - 0.0466R_x$ 0.189
Lens	$3.557 + 0.0563R_x$ 0.095	$3.547 + 0.0531R_x$ 0.093	$3.572 + 0.0595R_x$ 0.096	$3.461 + 0.0207R_x$ 0.054	$3.448 + 0.0235R_x$ 0.072	$3.477 + 0.0196R_x$ 0.046
Vitreous	$16.200 - 0.3376R_x$ 0.234	$16.375 - 0.3574R_x$ 0.272	$15.951 - 0.3034R_x$ 0.213	$16.715 - 0.3572R_x$ 0.524	$16.903 - 0.4014R_x$ 0.602	$16.497 - 0.3373R_x$ 0.548
Total*	$23.288 - 0.3799R_x$ 0.272	$23.481 - 0.3923R_x$ 0.319	$23.014 - 0.3540R_x$ 0.264	$23.819 - 0.3793R_x$ 0.540	$24.053 - 0.4220R_x$ 0.624	$23.549 - 0.3643R_x$ 0.583
Radii of curvature, mm						
Cornea†	$+7.787 + 0.0095R_x$ **0.002**	$+7.841 + 0.0078R_x$ **0.001**	$+7.711 + 0.0141R_x$ **0.004**	$+7.819 + 0.0178R_x$ 0.022	$+7.877 + 0.0106R_x$ 0.008	$+7.751 + 0.0187R_x$ 0.027
Anterior lens†	$+9.090 - 0.0487R_x$ 0.008	$+9.222 - 0.0617R_x$ 0.014	$+8.904 - 0.0251R_x$ **0.002**	$+9.870 - 0.0620R_x$ 0.036	$+10.052 - 0.0930R_x$ 0.075	$+9.661 - 0.0520R_x$ 0.034
Posterior lens†	$-5.454 + 0.0292R_x$ 0.008	$-5.534 + 0.0370R_x$ 0.014	$-5.342+ 0.0151R_x$ 0.002	$-5.922 + 0.0372R_x$ 0.036	$-6.031 + 0.0558R_x$ 0.075	$-5.797 + 0.0312R_x$ 0.034
Refractive indices						
Cornea/anterior chamber	1.333...	1.333...	1.333...	1.333...	1.333...	1.333...
Lens	1.416	1.416	1.416	1.416	1.416	1.416
Vitreous	1.333...	1.333...	1.333...	1.333...	1.333...	1.333...
Powers, D						
Cornea†	$42.808 - 0.0522R_x$	$42.513 - 0.0423R_x$	$43.232 - 0.0791R_x$	$42.636 - 0.0971R_x$	$42.319 - 0.0570R_x$	$43.011 - 0.1038R_x$
Lens, equivalent†	$23.920 + 0.1209R_x$	$23.588 + 0.1508R_x$	$24.400 + 0.0619R_x$	$22.069 + 0.1354R_x$	$21.699 + 0.1971R_x$	$22.532 + 0.1181R_x$
Maximum absolute error in vitreous chamber depth for −5 to +5-D refraction range, mm	0.1	0.11	0. 09	0.08	0.14	0.06

The top line in each cell is the regression equation of refraction, and the second line is R^2 of the regression. Nonsignificant correlations are bolded. R_x is spherical equivalent refraction in the spectacle plane 12 mm in front of the cornea.

* Sum of preceding components.

† Obtained from cornea or lens radii of curvature fits.

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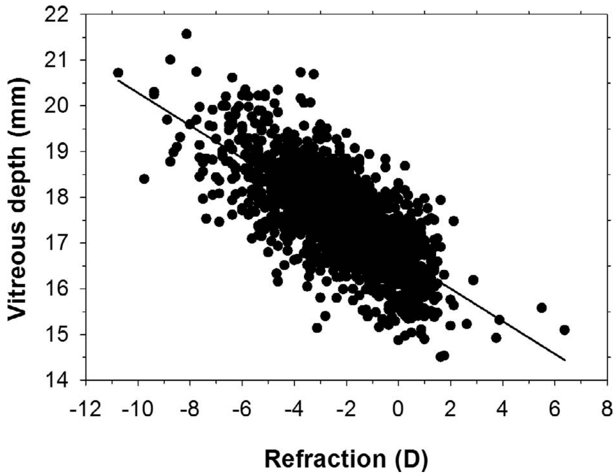

Figure 1. Vitreous chamber depth as a function of refraction for all 14-year-old children (R^2 0.52, $P < 0.0001$).

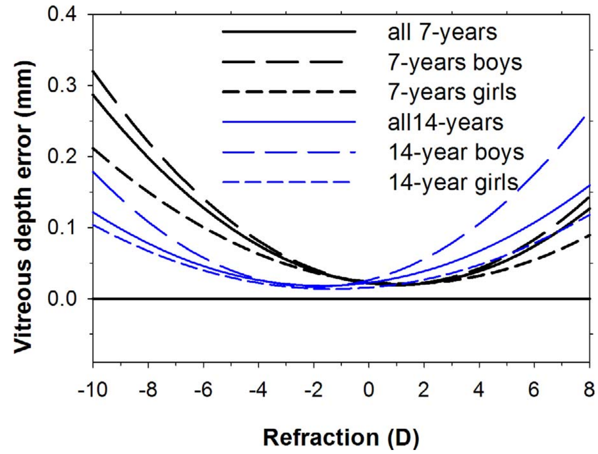

Figure 2. Errors in vitreous chamber depth of refraction-dependent 7- and 14-year-old schematic eyes.

significantly with refraction. Accordingly we used constant values for corneal thickness. Linear fits were used for all other parameters, although it must be pointed out that for 7-year-old children and their separate sexes, the corneal power did not change significantly with refraction. The highest correlations were for vitreous chamber depth (R^2 0.21–0.60) and axial length (0.26–0.62), followed by anterior chamber depth (0.15–0.22), lens thickness (0.05–0.10), lens surface radii of curvature (0.002–0.08), and corneal radius of curvature (0.001–0.03). The correlations for vitreous chamber depth and axial length were higher for the 14-year-old group than for the 7-year-old group. Figure 1 gives an example of high correlation.

Calculated errors in vitreous chamber depth (mismatches between measured and calculated values) are shown in Figure 2. Across the six different subject groups, the maximum absolute errors ranged from 0.06 to 0.14 mm within the refraction range of −5 to +5 D (Table 1).

The rate of change in vitreous chamber depth with change in refraction ranges from −0.30 to −0.40 mm/D, similar to results in other studies.[4,8,12] Boys had greater rates of change in vitreous chamber depth and lens power with changes in refraction than girls, with the finding concerning the vitreous chamber depth expected on the basis of the longer eyes of boys requiring greater length change to achieve the same refraction change.

The rates of change in anterior chamber depth and lens thickness with change in refraction were greater for 7- than for 14-year-old children, with approximately half of the increases in anterior chamber depth with refraction compensated for by reductions in lens thickness.

Concerning sex and age, corneal thickness, anterior chamber depth, vitreous chamber depth, and axial length were greater in boys and older children; corneal power was greater in girls; and lens thickness and lens power were greater in girls and in younger children, matching results previously reported.[3,4,8]

Figure 3 shows model eyes corresponding to emmetropia and 5-D myopia for both age groups.

Emmetropes

For the emmetropic children and in both age groups, central corneal thickness and corneal curvature were normally distributed ($P > 0.05$), but anterior chamber depth, lens thickness, vitreous chamber depth, and axial length had nonnormal distributions ($P < 0.05$).

Table 2 shows summary data both for age groups and for sexes. There were significant statistical differences between the sexes for all biometric parameters ($P < 0.001$) except for corneal thickness and lens thickness. Boys had longer anterior chambers, vitreous chamber depth and axial lengths, less powerful corneas and lenses, and thinner lenses than girls. There were significant statistical differences between the age groups for all biometric parameters ($P < 0.001$) except corneal power and corneal radius of curvature. The older group had longer distances except for lens thickness (shorter) and less powerful lenses than the younger group. Most sex differences were similar at the two ages.

Table 3 summarizes the parameters for all six emmetropic schematic eye models, and Figure 4 illustrates the four sex-based models. Note the following departures from mean data. Some of the corneal radii of curvature were adjusted so that the sex-related differences were the same for both ages (maximum change 0.02 mm). The anterior chamber depth for 7-year-old girls was changed from 2.96 to 2.97 mm so that boys and girls would both be 0.03 mm away from the non-sex-based model. The vitreous chamber depth and axial length of 7-year-old children were increased by approximately 0.06 mm, largely to compensate for the approximately +0.10 D mean refractions of the group. The vitreous chamber depth and axial length of 14-year-old children were reduced by 0.03 mm. Refractions of the model eyes ranged from −0.01 to +0.03 D.

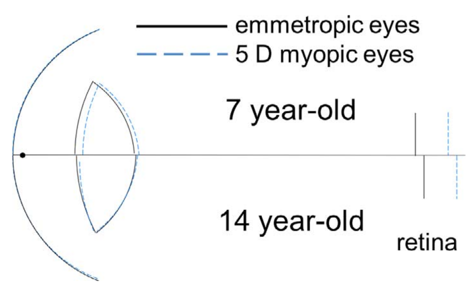

Figure 3. Eye models for emmetropic and 5-D myopic eyes for (*top*) 7-year-old and (*bottom*) 14-year-old age groups. These are determined from linear fits of parameters as a function of refraction. While these are three refractive surface eye models (anterior cornea and two lens surfaces), the position of the posterior cornea is indicated by a *dot*.

Table 2. Summary of Refraction and Biometric Data for Emmetropic Eyes

	All 7-Year-Olds, 318*		7-Year-Old Boys, 184		7-Year-Old Girls, 133		All 14-Year-Olds, 197		14-Year-Old Boys, 102		14-Year-Old Girls, 95	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age, y	7.1	0.4	7.1	0.4	7.0	0.3	13.7	0.6	13.7	0.5	13.7	0.6
Refraction, D	0.11	0.24	0.10	0.24	0.13	0.25	0.01	0.25	0.04	0.25	−0.01	0.26
Distances, mm												
Cornea‡	0.541	0.032	0.542	0.031	0.539	0.027	0.547	0.030	0.549	0.033	0.545	0.028
Anterior chamber†‡	3.03	0.20	3.08	0.21	2.96	0.20	3.08	0.22	3.02	0.21	3.14	0.21
Lens‡	3.55	0.17	3.54	0.18	3.56	0.19	3.46	0.24	3.45	0.16	3.48	0.31
Vitreous†‡	16.14	0.62	16.28	0.60	15.94	0.59	16.65	0.71	16.81	0.70	16.47	0.68
Total†‡	23.23	0.62	23.39	0.60	23.00	0.60	23.73	0.74	23.95	0.72	23.49	0.69
Radii of curvature, mm												
Cornea†	+7.78	0.25	+7.83	0.24	+7.71	0.24	+7.79	0.27	+7.86	0.27	+7.72	0.24
Powers, D												
Cornea (4/3 index)†	42.90	1.39	42.60	1.33	43.30	1.38	42.82	1.46	42.45	1.47	43.22	1.35
Lens†‡	24.06	1.44	23.84	1.38	24.36	1.48	22.24	1.51	21.96	1.51	22.54	1.47

* Sex of one child not available.
† Significant sex difference.
‡ Significant age difference.

Discussion

Using the data for the Anyang Childhood Eye Study for grade 1 and grade 8 children,[6,10] we have designed three-surface emmetropic eye models for 7- and 14-year-old Chinese children with a relatively large sample size. These model eyes support the results reported previously.[7,8,12–15] There was considerable growth between 7 and 14 years, and this was similar for both sexes. Anterior chamber depth increased by 0.08 mm, although this was balanced by a decrease in lens thickness of 0.09 mm; vitreous chamber depth and axial length increased by 0.5 mm, and lens power decreased by 1.9 D. There were considerable differences between the sexes, with boys having deeper anterior chambers than girls by 0.1 mm, greater vitreous chamber depths by 0.3 mm, greater axial lengths by 0.4 mm, lower corneal powers by 0.8 D, and lower lens powers by 0.5 D.

In general, the emmetropic models give biometric parameters similar to those derived from the refraction-dependent models. The latter are given in parentheses in Table 3. The discrepancies are greater for the 14-year-old group than for the 7-year-old group, probably because the mean refraction of the former is farther away from emmetropia (−2.1 ± 2.1 D compared with +0.9 ± 1.0 D). For the 14-year-old children, the refraction-dependent models overestimate vitreous chamber depth and axial lengths by approximately 0.1 mm, underestimate corneal powers by approximately 0.2 D, and underestimate the lens powers by 0.0 to 0.3 D.

Table 3. Emmetropic Eye Models

	7-Year-Olds	7-Year-Old Boys	7-Year-Old Girls	14-Year-Olds	14-Year-Old Boys	14-Year-Old Girls
Refraction, D	+0.02 (+0.01)	+0.01 (0.00)	+0.01 (+0.04)	−0.01 (−0.05)	+0.03 (−0.06)	−0.01 (−0.05)
Distances, mm						
Cornea†	0.54 (0.54)	0.54 (0.54)	0.54 (0.54)	0.55 (0.55)	0.55 (0.55)	0.55 (0.55)
Anterior chamber*†	3.00 (2.99)	3.03 (3.02)	2.97 (2.95)	3.08 (3.09)	3.14 (3.15)	3.02 (3.03)
Lens†	3.55 (3.56)	3.55 (3.55)	3.55 (3.57)	3.46 (3.46)	3.46 (3.46)	3.46 (3.46)
Vitreous*†	16.17 (16.20)	16.34 (16.38)	16.00 (15.95)	16.62 (16.72)	16.78 (16.90)	16.44 (16.50)
Total*†	23.26 (23.29)	23.46 (23.48)	23.06 (23.01)	23.69 (23.82)	23.93 (24.05)	23.47 (23.54)
Radii of curvature, mm						
Cornea*	+7.78 (+7.79)	+7.85 (+7.84)	+7.72 (+7.70)	+7.78 (+7.82)	+7.85 (+7.88)	+7.71 (+7.75)
Anterior lens*†	+9.04 (+9.09)	+9.12 (+9.22)	+8.93 (+8.90)	+9.78 (+9.87)	+9.91 (+10.05)	+9.65 (+9.66)
Posterior lens*†	−5.42 (−5.45)	−5.47 (−5.53)	−5.36 (−5.34)	−5.87 (−5.92)	−5.94 (−6.03)	−5.79 (−5.80)
Refractive indices						
Cornea/anterior chamber	1.333...	1.333...	1.333...	1.333...	1.333...	1.333...
Lens	1.416	1.416	1.416	1.416	1.416	1.416
Vitreous	1.333...	1.333...	1.333...	1.333...	1.333...	1.333...
Powers, D						
Cornea*	42.84 (42.81)	42.52 (42.51)	43.18 (43.23)	42.84 (42.64)	42.52 (42.32)	43.18 (43.01)
Lens, equivalent*†	24.05 (23.92)	23.83 (23.59)	24.29 (24.40)	22.24 (22.07)	21.98 (21.70)	22.55 (22.53)

Numbers in parentheses are derived from the linear fits in Table 1.
* Sex dependent.
† Age dependent.

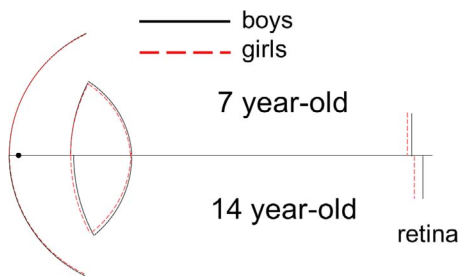

Figure 4. Emmetropic eye models for (*top*) 7-year-old boys and girls and (*bottom*) 14-year-old boys and girls. These are determined from means of parameters of emmetropic children, with some modification as described in the text. While these are three refractive surface eye models (anterior cornea and two lens surfaces), the position of the posterior cornea is indicated by a *dot*.

Atchison[16] developed three-surface paraxial schematic emmetropic eye models based on data for 106 healthy emmetropic eyes of Caucasian subjects aged from 18 to 69 years.[17] Sex differences were similar in his and the present study. With increase in age in his adult schematic emmetropic eye models, anterior chamber and vitreous chamber depths, anterior lens radius of curvature, and lens equivalent power all decreased, while lens thickness and axial length increased. However, in the present study using children, we found the opposite trends for anterior chamber depth, vitreous chamber depth, and the estimates of anterior lens radius of curvature. The difference in trends is partly due to thinning of the lens during childhood, followed by gradual thickening during adulthood.[18]

Another modeling investigation developed four-surface refraction-dependent schematic eyes based on data for 121 healthy young Caucasian adult eyes[19]; sex differences were not investigated. The only refraction-dependent preretinal parameters that changed were anterior corneal radius of curvature, vitreous chamber depth, and axial length. The rate of change of the radius of curvature with refraction was slightly higher than those reported for the 14-year-old eyes, together with a higher correlation coefficient (adjusted $R^2 = 0.05$ compared with $R^2 = 0.01–0.03$). The rates of change of the lengths with refraction in the adult study were slightly lower than for the eyes here, with adjusted R^2 values in the former similar to the R^2 values for the 14-year-old eyes. The failure in the adult study to find other variables (anterior chamber depth, lens thickness, and lens power) significantly associated with refraction may relate to small sample size, that is, 131 participants compared with 3995 in this study.

Mutti et al.[18] found that lens thinning in early childhood ceased after 10 years of age, while axial length continued to grow throughout childhood. Wong et al.[20] found that anterior chambers deepened until 9 or 10 years of age and then became shallower as myopic and emmetropic children grew older. These findings support the difference in anterior chamber depth and lens thickness between our schematic eyes and those in Atchison's adult study,[19] which indicates that lens thinning plays an important role in the development of refractive error in early childhood.

In a study by Zadnik et al.,[21] lens power decreased by 2.1 D between 6 and 14 years (88% white), whereas in our study of Chinese children lens power decreased by 1.9 D between 7 and 14 years (Table 1). In the study by Zadnik et al., the anterior chamber depth elongated by a mean 0.19 mm and axial length elongated by a mean 0.7 mm between 6 and 14 years, but the respective changes of our two groups were smaller at 0.08 mm and 0.5 mm, respectively. These comparisons suggest that our schematic eyes may not work as well for other ethnic groups due to differences in ocular components. However, the schematic eyes will be helpful for analyzing longitudinal or transverse changes of ocular components in Chinese children living in different places in China as well as in other places of the world.

There are limitations to the data collection protocol and the schematic eyes in this study. Firstly, we used noncycloplegic ocular biometric data and cycloplegic refraction. Compared with noncycloplegia, cycloplegia gives greater anterior chamber depth,[22,23] lower vitreous chamber depth,[22] and lower lens thickness[22] in children. Secondly, in the absence of lens data, we used a lens model with a fixed relationship between the lens surface powers and an equivalent refractive index for the lens rather than gradient indices as used in more sophisticated models of the lens.[24] Thirdly, the use of linear correlations may be oversimplistic, as the results describing the relation between biometric parameters and refraction have low correlations in most cases. Fourthly, our models cannot predict optical aberrations and off-axis (peripheral) refractions.[25] We do not have sufficient information, such as surface asphericity and retinal curvature, to allow such analyses.

In summary, we have developed paraxial schematic eye models for 7- and 14-year-old Chinese children. To our knowledge, these are the first models of young children's eyes. They may be useful in myopia research, as would the development of additional wide-angle schematic eye models taking into account peripheral refraction data.

Acknowledgments

The authors thank the Anyang city government for its support in helping to organize the survey. We'd like to express our sincere appreciation to Grand Seiko Co., Ltd. for the prompt response and great troubleshooting service for WAM-5500 Auto Refractor/Keratometer during the study.

Supported by the National Natural Science Foundation of China (81300797); the Major International (Regional) Joint Research Project of the National Natural Science Foundation of China (81120108007); the Major State Basic Research Development Program of China ("973" Program, 2011CB504601) of the Ministry of Science and Technology; Beijing Nova Program (Z121107002512055); and Australian Research Council Discovery Grant DP110102018. The authors alone are responsible for the content and writing of the paper.

Disclosure: **S.-M. Li**, None; **N. Wang**, None; **Y. Zhou**, None; **S.-Y. Li**, None; **M.-T. Kang**, None; **L.-R. Liu**, None; **H. Li**, None; **Y.-Y. Sun**, None; **B. Meng**, None; **S.-Y. Zhan**, None; **D.A. Atchison**, None

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